Studies and Transactions on Pollution Assessment of the Lagos Lagoon System, Nigeria

Babajide Alo, Kehinde Olayinka, Aderonke Oyeyiola, Temilola Oluseyi, Rose Alani, and Akeem Abayomi

Abstract

The Lagos Lagoon system is a brackish coastal lagoon—the largest in the West African coast with a large series of estuaries—located between longitude 3°23′ and 3°40′E and between latitude 6°27′ and 6°48′N. It is a shallow expanse of water (0.3–3 m deep), 50 km long and 3–13 km wide and separated from the Atlantic Ocean by a narrow strip of barrier bar complex. This report is on the levels of pollution and nutrients status of the Lagos Lagoon system including physicochemical properties, pesticides organochlorines (OC), polyaromatic hydrocarbons (PAHs), heavy metal species and nutrients observed between 2002 and 2008. Watersheds of the highways on the lagoon had higher concentrations of nutrients (phosphorus and nitrates) relative to other locations on the Lagoon. The western part of the Lagoon was found to have higher concentrations of Cd, Cu, Pb and Zn than the other points. Lagos Lagoon and the adjoining creeks show high anthropogenic input of PAHs and other persistent organic pollutants (POPs). The major hydrocarbon index in most samples was at C_{29}, C_{31} and C_{27}, indicating vascular plants sources. Mean PBT levels in water and in sediment increased with time between 2004 and 2007. PBT distribution in the lagoon followed the pattern, sediment > biota > water, though some exceptions occurred where the biota bioaccumulated more PBTs than are found in both sediment and water. The Lagoon biota bioaccumulated organochlorine pesticides above allowable limits and thus pose a high risk to human health. The levels of some pollutants in the Lagoon have negatively impacted on the environmental quality which has indirectly affected the social and economic activities of the dependants and this requires improved management strategies to ameliorate. Indeed with the high population that the estuary/lagoon system supports, consideration for its designation as an international waterbody and its concomitant attention is now paramount.

Keywords

Lagos Lagoon • Heavy metals • Pollution • Nutrients • Polyaromatic hydrocarbons • Organochlorine pesticides • Polychlorinated biphenyls • Hydrocarbons

Introduction

Urbanization and industrialization have led to the release of a variety of pollutants from both point and diffuse sources, and has placed considerable pressure on the aquatic resource. This is of particular concern in developing countries where expansion of urban area may be relatively

B. Alo (✉) · K. Olayinka · A. Oyeyiola · T. Oluseyi · R. Alani · A. Abayomi
Analytical and Environmental Research Group, Department of Chemistry, University of Lagos, Akoka, Lagos, Nigeria
e-mail: profjidealo@yahoo.com

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unregulated and where environmental protection may be inadequate (Fonesca et al. 2011; Li et al. 2007; Manning 2011; Nriagu 1992; Oyeyiola et al. 2013a). The ocean's ecosystem and the changes in it induced by pollution and climate change are of worldwide concern. To predict how this ecosystem will respond to further global change and what role the ocean's biota will play requires detailed studies of biological, physical and chemical data of marine-related sample matrices (water, sediment and biota). One of the main concerns at present is the pollution of the marine environment by contaminants whose levels are growing at an alarming rate. Pollutants such as potentially toxic metals, persistent organic pollutants such as pesticides, dioxins, polychlorinated biphenyls and PAHs, and nutrients have been found to be a major threat to the marine ecosystem and thus a major global problem. This is because pollutants released in one part of the world can be transported to regions far from their source of origin through the atmosphere, waters and other pathways. Their effect on human health can be felt directly and/or via the food web (Chaney et al. 1996).

The Lagos Lagoon System

Lagos is the Africa's biggest city and the fastest growing metropolis in the world. It is the most heavily industrialized and urbanized city in Nigeria, with much of the nation's wealth and economic activities located there, and 12 % of the total population (150 million). The City of Lagos is currently undergoing an extensive programme of expansion and development with the aim of becoming a 'megacity' and major international focus for trade and industry (Howden 2010; This Day's Special International Project 2007). The urban area is built on a number of floodplains and encompasses a network of marshes, swamps, streams, creeks, rivers and estuaries which receive large quantities of rain water run-off, domestic, municipal and industrial waste effluents, and each of these receptors discharge finally into the Lagos Lagoon. We describe here the entire hydrological system of the Lagos Lagoon System in Nigeria.

The city of Lagos has about 91 waterways (canals) and their tributaries draining the entire city and discharging into the Lagos Lagoon at different locations. Most of the major markets and industries in Lagos (Iddo, Otto, Yaba, Oshodi, Mushin, Idioro, Balogun, Ebute–Ero, Idumota, Abule Egba, Alaba Rago, Alaba International, Mile2 and Mile 12 markets) generate huge quantities of municipal wastes which are either dumped directly into the lagoon or are incinerated at sites that drain into the lagoon at different locations. Open waste incineration, in some cases on the shores of Lagos lagoon, is a very common sight in Lagos. One of such open incinerators is found at Okobaba, where incessant burning of sawdust and other municipal waste take places near the Third Mainland Bridge—the longest bridge in West Africa which crosses the Lagos lagoon and links the Lagos Mainland in the north of Lagos Megacity to the Lagos Island in the south of the city.

The Lagos Lagoon is a brackish coastal lagoon—the largest in the West African coast—located between longitude 3°23′ and 3°40′E and between latitude 6°27′ and 6°48′N. It is a fairly shallow expanse of water (0.3–3 m deep) which is about 50 km long and 3–13 km wide and separated from the Atlantic Ocean by a narrow strip of barrier bar complex. The lagoon borders the forest belt and empties directly into the Atlantic Ocean at the harbour (Fig. 1). During the rainy season, large volumes of fresh water passes through the harbour into the sea. In view of its complexity (linkages to land, freshwater, sea, salinity fluctuations, dynamics), the lagoon is a fragile ecosystem prone to environmental degradation through pollution from industry, household, resource over-exploitation, etc. The loading of pollutants into the lagoon affects the quality of the water. This is reflected in the colour and appearance of the lagoon water, ranging from oily at some locations to grey, slightly yellow, turbid and dark at others. There is a high spatial and temporal variability of constituents (pollutants) in surface sediments throughout the lagoon. This is reflected by the variation in sediment type and colour at different locations of the lagoon.

Lagos lagoon serves the huge population of Lagos, approximately 15 million. The Lagoon finds its use in artisanal fishing, transport and recreational purposes. It is an important habitat for a wide array of fish and marine organisms and is the major source of sea foods for the people of Lagos (Isebor et al. 2006). Some abuses of the Lagoon include serving as a direct dumpsite for industrial, agricultural and municipal wastes, and even a dumpsite for sewage at some locations. Dredging of sediment from the lagoon for sand-filling and land reclamation although illegal is commonplace to satisfy local demand for building constructions. Pollutants from this lagoon may affect the population directly through contact with contaminated sediment or water and via the food chain.

However, despite rapid industrialization in the region, coupled with the importance of this waterbody, currently, there is a dearth of detailed information on the pollution and pollutant status of the Lagos Lagoon system.

Physicochemical Properties of the Lagos Lagoon

Our extensive studies of the physicochemical status of the water in the Lagos Lagoon System have been revealing on the pollution status of the waterbody. Water samples

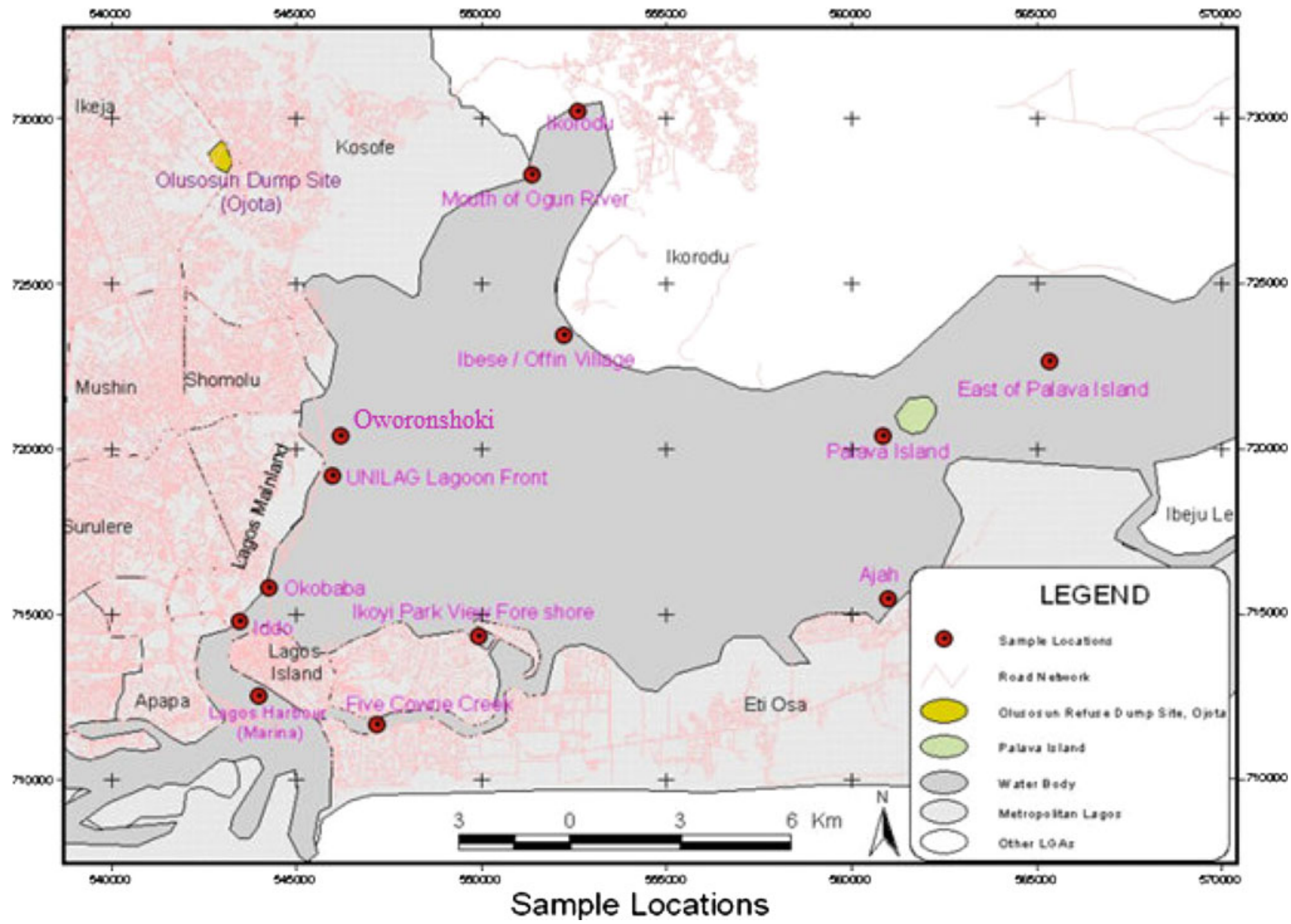


Fig. 1 Map showing the Lagos Lagoon

Table 1 Physico-chemical properties of water samples from the Lagos Lagoon

	Sampling points					WHO limit
Parameter	Q	R	S	COW	PAL	
Dissolved oxygen (mg O_2/l)	4.7–6.3	3.7–5.4	3.4–5.0	6.2–6.5	6.1–6.4	–
BOD (mg O_2/l)	11.8–30.4	16.8–24.4	22.2–34.2	16.2–28.6	14.2–20.6	0
Total hardness (mg $CaCO_3$/l)	191.8–2,057.3	146.8–1,783.8	149.1–916.3	65.8–102.8	21.5–96.2	–
Total Alkalinity (mg $CaCO_3$/l)	61.5–01.7	74.9–9.0	80.3–91.0	42.7–60	32.3–40	–
Acidity (mg $CaCO_3$/l)	[a]–9.3	3.0–11.7	2.5–12.8	5.5–7.0	5.1–6.5	–
Chloride (mg/l)	798.9–14,819	1520.6–11,752	283.5–12,722.7	587.2–5,541	432.8–1,318.2	250
Sulphate (mg/l)	303.6–2,432.9	343.4–22,430	32.0–2,343	43.2–1,220	87.6–93.9	–
Phosphate (mg P/l)	0.2–0.4	0.1–0.3	0.2–0.3	0.1	0.1	1.0
Conductivity ($\mu S\ cm^{-1}$)	24 000–410,000	21,000–315,000	3,000–330,000	2,500–170,000	1,300–60,000	–
pH	6.9–8.2	6.9–7.8	6.9–7.5	7.0–7.2	7.2–7.4	6.5–8.5
Total solids (mg/l)	3,100–30,870	3,910–25,630	2,080–23,780	1,720–11,080	980–3,070	500
Total dissolved solids (mg/l)	2,000–28,580	3,070–24,060	1,500–21,850	850–10,840	240–1,220	500

[a] Not detected

Q Iddo, *R* Oko-Baba, *S* Oworonshoki, *COW* five cowrie, *PAL* Palaver Island

Table 2 Concentration of nutrients in the sediments of Lagos Lagoon System

Sampling location	Total PO_4^{3-}–P (Mean ± SD) (mg kg^{-1})	Bioavailable PO_4^{3}–P (Mean ± SD) mg kg^{-1}	Percent bioavailable (%)	NO^{2-}/NO^{3} (Mean ± SD) (mg kg^{-1})	P:N Ratio
Akoka	326.6 ± 15.2	4.65 ± 0.76	1.42	11.24 ± 0.38	0.41
Okobaba	619.3 ± 33.4	7.45 ± 0.26	1.2	0.92 ± 0.06	8.1
Iddo	1,203.9 ± 171.6	20.94 ± 0.62	1.74	0.71 ± 0.08	29.49
Ijora	253.5 ± 100.8	4.52 ± 0.52	1.78	6.56 ± 0.12	0.69
Leventis	65.9 ± 31.8	9.48 ± 0.84	14.38	4.43 ± 0.12	2.14
Cowry Creek	174.5 ± 96.0	8.90 ± 0.78	5.1	9.85 ± 0.32	0.9
Falomo	637.2 ± 4.2	17.03 ± 0.28	2.67	0.56 ± 0.08	30.36
Mean	468 ± 387	10.4 ± 6.2	4.0 ± 4.8	4.90 ± 4.47	10.3

collected from the Lagos Lagoon between January 2004 and March 2005 were analysed, and all physicochemical parameters were determined. Table 1 gives the results for physicochemical properties of the water samples collected from different parts of the Lagos lagoon. Points Q, R and S are Iddo, Oko-Baba and Oworonshoki, respectively, by (Fig. 1) and are close to human activities, while Cow (Five Cowrie Creek) and PAL (Palavar Island) are points on the Lagos Lagoon that are far from industrial or domestic activities.

The dissolved oxygen (DO) at points Q, R and S appeared to be independent of tide or seasons and is suitable for aquatic life to survive. This is because in spite of pollution of the water by sewage and other domestic wastes, the impact of the pollution is not felt because of the relatively large volume of water in the Lagos Lagoon which facilitates dilution of the pollutants. The highest DO values were observed at COW and PAL which are far from human and industrial activities.

The biochemical oxygen demand (BOD) values for points Q and S were the highest. This was probably because of the untreated sewage discharged into the Lagos Lagoon at point Q, and industrial effluents and domestic wastes at point S which may contain high level of organics.

The chloride content of the water is expectedly high. This is due to the presence of chloride salts in the sea water which flows into the Lagos lagoon when the tide is high. The pH range at all the points fall within the WHO limit for unpolluted water (6.5–8.5).

Generally, points Q, R and S were more polluted than COW and PAL in terms of the DO, BOD and pH values of the samples collected. This may be because domestic wastes are discharged into the Lagos lagoon at these points.

Nutrients Status in the Sediments of Lagos Lagoon System

Abayomi et al. (2011) reported on the potential of the Lagos lagoon sediment to act as a sink for anionic nutrient from highway run-off and roadside soils contiguous to the lagoon system. Concentrations of total phosphorus ranged from 73 ± 20 to 622 ± 514 mg kg^{-1} in the wet season and 170 ± 10 to 1,320 ± 480 mg kg^{-1} in the dry season. The bioavailable concentration had a range of 2.57 ± 0.64 to 9.4 ± 5.1 mg kg^{-1} and 4.8 ± 0.7 to 22.0 ± 0.9 mg kg^{-1} for the wet and dry season, respectively. The concentrations of bioavailable NO^{2-}/NO^{3-} in the roadside samples ranged from 0.53 ± 0.64 to 12.35 ± 32.88 mg kg^{-1} for the wet season and 0.39 ± 0.08 to 21.35 ± 0.50 mg kg^{-1} for the dry season. In the Lagoon sediment, phosphorus had a mean concentration range of 468 ± 387 mg kg^{-1} total phosphorus and 10.4 ± 6.2 mg kg^{-1} bioavailable phosphorus for the sampled locations (Table 2). Watersheds of the highways on the lagoon had higher concentrations of these nutrients relative to other locations on the Lagoon which confirm roadside as soils as sources of nutrient input into the Lagos Lagoon.

Average Phosphate Concentration in the Lagos Lagoon

Results from the study showed a mean bioavailable phosphate concentration range of 0.046–0.91, 0.046–0.453 and 0.048–0.492 mg L^{-1}, respectively, for the top, middle and bottom strata of the lagoon. Mean total phosphate concentrations were in the range of 0.054–0.513, 0.041–0.961 and

0.058–1.71 mg L^{-1} for the top, middle and bottom strata, respectively (Figs. 2, 3).

In most cases, the levels observed were higher than the 0.04 PO_4^{3}—P limit and above this concentration algal bloom starts to occur (Wallace et al. 2010).

Potentially Toxic Elements in Sediments of the Lagos Lagoon System

In a 2006 study, our group collected surface sediments from the Lagos Lagoon, Nigeria, and three adjoining rivers/estuaries (Odo-Iyaalaro River, Shasha River and Ibeshe River) and these were analysed for their physicochemical properties, pseudo-total concentration, fractionation pattern as well as the ecotoxicological implication of the potentially toxic metals (PTM): Cd, Cr, Cu, Pb and Zn.

According to Oyeyiola et al. (2013a), the Odo-Iyaalaro River was observed to be the most polluted river, with highest concentrations of 42.1, 102, 185, 154 and 1040 mg kg^{-1} of Cd, Cr, Cu, Pb and Zn, respectively. The month of March, which is the peak of the dry season, had particularly higher concentration of metals compared with samples collected from the same point in other months. This was attributed to the accumulation of these PTMs in sediment during the dry season, which are then remobilised during the rainy season. In their study, it was reported that previous workers observed seasonal influence on sediment metal concentrations in tropical systems, but findings are contradictory. Similar to their study, Bahena-Manjarrez et al. (2002) observed the highest metal concentrations in the dry season in the Coatzacoalcos River, Mexico, and this was supported by Alagarsamy (2006) who reported the lowest metal concentrations during the monsoon in the Mandovi estuary, India.

Oyeyiola et al. (2013b) also found potentially toxic elements (PTE) concentrations in sediments from the Shasha River to decrease with decreasing distance from the Lagos Lagoon. This variation was said to correlate with the location of industries and their waste-disposal systems. The average concentrations of PTE in the Shasha River were lower than in the Odo-Iyaalaro River. The Ibeshe River was the least contaminated, apart from a site affected by Cu from the textile industry. The concentration of Cu was also found to decrease downstream with increasing distance into the Lagos Lagoon.

They also observed in their studies that the western part of the Lagoon had higher concentrations of the studied metals than the other parts. This was in agreement with researchers (Otitoloju et al. 2007) who also observed higher concentration of metals in the western part of the lagoon. These may be because there are a lot of bridges around these area as compared with the other parts of the lagoon and also there is a lot of human activities. In our study, it was observed that Cr concentration in the Lagos Lagoon was generally high even though the range is small. This is probably an indication that Cr in the Lagos Lagoon is geogenic. There was no difference were observed between concentrations of metals in rainy and dry seasons in the lagoon, nor were there marked seasonal differences in grain size distribution, as had been observed in some of the tributary rivers. This was to be expected because according to Lund-Hansen et al. (1999), re-suspension rate was observed to be much more higher than sedimentation rate in shallow coastal lagoons and the depth of Lagos Lagoon waterbody means that deposition, as well as re-suspension, is likely to occur throughout the year.

Due to lack of legislation in Nigeria governing acceptable levels of PTE in sediments, it was not possible to assess or contextualise the current findings within a local regulatory framework, so the consensus-based probable effect concentrations (PEC) recommended by MacDonald et al. (2000) and Dutch sediment guideline (Grimwood and

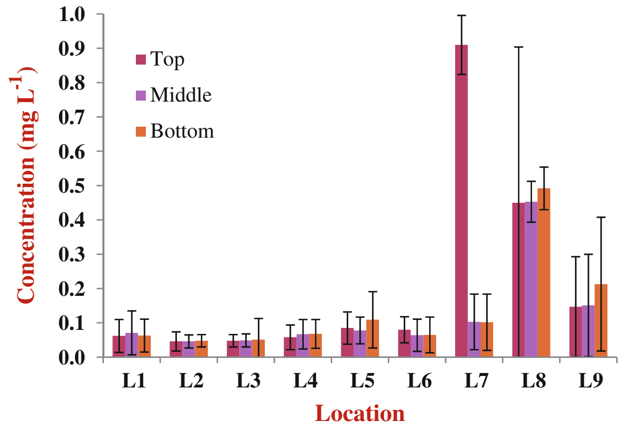


Fig. 2 Average concentration of bioavailable phosphate in the water of the Lagos Lagoon

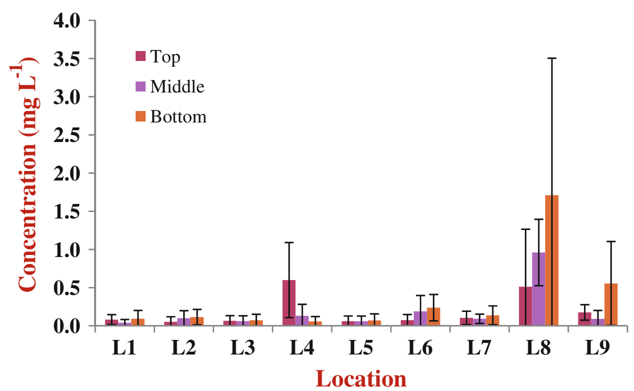


Fig. 3 Average concentration of total phosphate in the water of the Lagos Lagoon

Table 3 Descriptive statistics of physicochemical properties and PTM concentration in sediments of dry and rainy seasons

Parameter	Dry			Rainy		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Odo-Iyaalaro						
pH	2.8	5.6	4.0	3.6	5.1	4.2
OM (%)	0.8	21	7.8	1.4	15.7	8.5
CEC	2.0	14.6	7.6	4.2	14.2	9.6
Cd (mg kg^{-1})	<0.9	42.1	9.6	<0.9	12.8	4.8
Cr (mg kg^{-1})	<17.5	102	31.0	<17.5	28.9	22.9
Cu (mg kg^{-1})	15.6	185	60.9	15.8	105	55
Pb (mg kg^{-1})	<15.8	154	56.7	21.6	108	63.5
Zn (mg kg^{-1})	53.1	1,040	292	18.7	377	147
Shasha River						
pH	4.3	7.3	5.6	4.2	7.7	6.2
OM (%)	0.1	8.2	2.4	0.2	7.4	2.1
CEC	1.6	9.8	3.9	1.6	10.2	3.8
Cd (mg kg^{-1})	< 0.9	1.2	0.9	<0.9	1.7	1.0
Cr (mg kg^{-1})	<17.5	56.7	27.8	<17.5	140	40.6
Cu (mg kg^{-1})	< 2.8	78.5	31.3	<2.8	106	32.0
Pb (mg kg^{-1})	< 15.8	189	38.6	<15.8	202	45.5
Zn (mg kg^{-1})	1.7	467	101	13	641	104
Ibeshe River						
pH	3.6	7	5.1	3.2	7.3	4.5
OM (%)	0.3	7.2	2.3	0.2	7.6	2.4
CEC	1.6	4.2	2.5	1.8	5.2	3.0
Cd (mg kg^{-1})	<0.9	<0.9	0.9	<0.9	<0.9	0.9
Cr (mg kg^{-1})	<17.5	48.3	27.1	<17.5	54.5	31.3
Cu (mg kg^{-1})	<2.8	332	62.0	<2.8	115	23.3
Pb (mg kg^{-1})	<15.8	26.3	16.2	<15.8	21.8	15.8
Zn (mg kg^{-1})	4.6	158	35.9	6.0	57.5	21.3
Lagos Lagoon						
pH	4.3	6.6	5.4	4.1	7.0	5.6
OM (%)	0.1	12.6	4.2	0.1	10.8	3.7
CEC	1.8	11.2	5.0	2	11.0	4.9
Cd (mg kg^{-1})	<0.9	2.1	1.2	<0.9	<0.9	<0.9
Cr (mg kg^{-1})	34.4	51.7	44.7	23.8	51.7	35.8
Cu (mg kg^{-1})	<2.8	33.7	20.6	<2.8	43.0	18.8
Pb (mg kg^{-1})	<15.8	39	28.4	<15.8	39.2	25.6
Zn (mg kg^{-1})	1.3	190	103	1.3	246	118

Dixon 1997) were used. Of the 103 sediments studied, 11 exceed the PEC for Cd (all in the Odo-Iyaalaro); two exceed the PEC for Cr; four exceed the PEC for Cu (one from Odo-Iyaalaro and three from Ibeshe River); three exceed the PEC for Pb and four exceed the PEC for Zn. Forty of the sediments were above the Dutch sediment guideline for Cu and four (three from Odo-Iyaalaro during the dry season) exceed the guideline for Zn.

In order to determine the mobility and bioavailability of the metals studied, BCR sequential extraction technique was used. In the Odo-Iyaalaro, cadmium and zinc showed a similarity in their fractionation pattern. They were mostly

Table 4 Ratios indicating predominant sources of POPs in Lagos lagoon

	Water (ng/mL)	Sediment (ng/g)	Crayfish ng/g)	Shrimp (ng/g)	Blue crab (ng/g)	Tilapia ng/g)	Megalops (ng/g)
∑PAHs	0.13	346.94	74.2	99.06	264.61	80.64	88.11
∑Lower PAHs	0.13	210.95	74.2	99.06	264.61	80.64	88.11
∑Higher PAHs	0	136	0	0	0	0	0
∑Low chlorinated PCBs	0	11.78	0.94	0.97	2.23	14.02	16.09
∑High chlorinated PCBs	0	3.25	0.33	0.78	44.15	17.32	29.85
∑PCBs	0	15.04	1.27	1.75	46.38	31.34	45.93
∑Ocs	0.02	2.79	21.03	8.41	69.4	39.94	32.09
PCBs/p,p'DDE	0	8.14		0.65	2.09	1.95	3.96
∑PAHs/∑PCBs		23.07	58.44	56.61	5.71	2.57	1.92

observed to be associated with the acid exchangeable fraction, while chromium and copper were observed to be associated with the reducible and oxidizable fractions, and lead with the reducible and residual fractions. Sediments with higher pseudototal metals contents often contained higher proportions of metals in more labile forms (released earlier in the BCR procedure). This is of environmental concern because it means that, where overall PTM concentrations are highest, the potential for remobilisation and uptake into the food chain is also greatest.

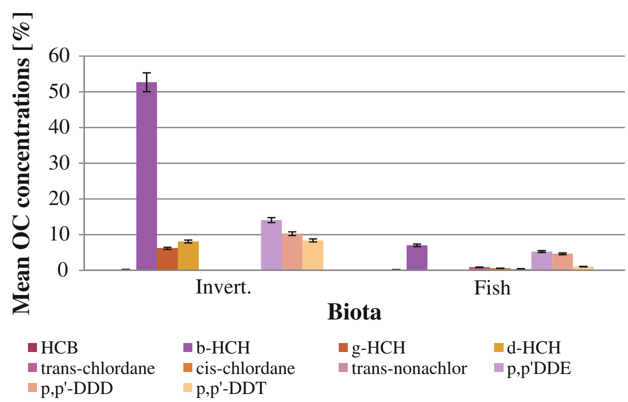


Fig. 4 Mean % OCs in fish and invertebrates

Ecotoxicological Risk Assessment of Sediments

In another study by Oyeyiola and Alo et al., the risk associated with the Lagos Lagoon system sediments was assessed using the risk assessment code (RAC). This was based on the percentage of acid exchangeable fraction of metals (i.e. the most mobile) determined with a sequential extraction procedure as per procedures developed by Davutluoglu et al. (2011), Jain et al. (2007), Perin et al. (1985). Based on these values, Cd was found in the Odo-Iyaalaro to be mostly associated with the very high-risk group. The other metals studied varied from no risk to medium risk, while zinc varied from high risk to very high risk in most of the sites in all the waterbodies.

The Hankanson potential ecological risk index was also used in the assessment (Cai et al. 2011; Hankanson 1980). In the absence of background values of metals in sediment in Nigeria, the background value of metals in sediment presented by the US National Oceanic and Atmospheric Administration (NOAA) (SQuiRTs 2008) was used, and the toxic-response factor presented by Cai et al. (2011) was also used. Cadmium was placed in the very high-risk category, thus posing the highest ecological risk in the Odo-Iyaalaro River (Table 3). The highest RI value was also observed during the dry season (March). Based on the ecological risk assessment, the researchers observed a need for strengthening environmental pollution control in other to prevent ecological risks from metals .

Persistent Organic Pollutants Sources and their Impacts on Lagos Lagoon, Nigeria

Studies in our laboratories have shown that industrial and other anthropogenic sources predominated over agricultural sources of Persistent Organic Pollutants (POPs) in the Lagos Lagoon (Alani et al. 2011). Also pyrolytic sources of PAHs were found to dominate natural or petrogenic sources in the Lagoon. This result agreed with Pazdro (2002), who reported that the occurrence of PAHs in the environment is

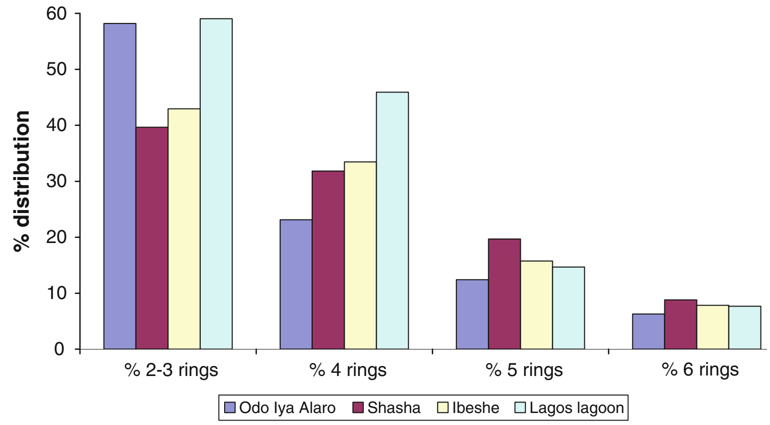


Fig. 5 Percentage distribution of grouped PAHs in all the sampling points

mainly due to combustion and pyrolysis of fossil fuels and to release into the environment of petroleum products. Environmentally, socially and economically, POPs have impacted the Lagos lagoon negatively. Exposure to POPs in the Lagos lagoon has negatively impacted human health by increasing the risks of most modern diseases among the inhabitants of Lagos (Table 4).

Bioaccumulation of Organochlorine Pesticide Residues in Fish and Invertebrates of Lagos Lagoon, Nigeria

Our studies have provided baseline information on the level of OCs in the Lagos Lagoon System including their bioaccumulation and the risk they pose to humans that depend on fish and invertebrates from the Lagos lagoon for food. The most bioaccumulated OCs in fish were beta-HCH (22.72–0.90 ng/g d. w.) and p,p'DDE (16.04–0.44 ng/g d. w.). The most bioaccumulative OCs in the invertebrates were still beta-HCH (24.50–16.10 ng/g d. w.) and p,p'DDE (22.20–1.85 ng/g d. w.). This agreed with the report that p,p'DDE was found to be more stable and persistent (refractory) than either p,p'DDT or p,p'DDD and underwent strong biomagnification with transfer along food chain (Walker 2009). The sum OCs of 55.22 ng/g d. w. in crab eggs, 63.90 ng/g d. w. in agaza (*Caranx hippos*) and 69.40 ng/g d. w. in young blue crabs (*Callinectus amnicola*) revealed these biota as the most contaminated. Beta-HCH and p,p'DDE were identified as the dominant OC in the Lagos lagoon. Consumption of crab eggs, mature crabs, young blue crabs (*Callinectus amnicola*) and Agaza (*Caranx hippos*), and some other seafoods from the Lagos lagoon could pose a high risk of OC health effects on humans as these biota bioaccumulated the contaminants above allowable limits (Fig. 4).

PAH Distribution in Sediments of the Lagos Lagoon System

Three trans-urban waterbodies of the Lagos lagoon system; Odo Iya alaro, Ibeshe and Shasha creeks that receive domestic, municipal and industrial effluents, and eventually empty into the Lagos Lagoon, were studied (Alani et al. 2012a). Sediment samples were collected bimonthly from 21 sampling points for a period of one year, covering both rainy and dry seasons of the year. The distribution of the PAHs in the sediment samples showed large variations in the sites investigated. The concentration of total PAHs ($\sum$PAHs) ranged from 9.76 to 6,448.66 μg/kg and showed a strong influence from anthropogenic inputs. In general, naphthalene, fluorene, phenanthrene, fluoranthene, pyrene, benzo (a) anthracene, chrysene, benzo (b) fluoranthene, and benzo (a) pyrene were the dominant PAHs found in the sediments.

The total PAH concentration for the Odo Iya alaro ranged from 268 to 6,449 μg/kg, Shasha creek ranged from 127 to 3,509 μg/kg, Ibeshe creek ranged from 56 to 2,996 μg/kg, while the Lagos lagoon ranged from 10 to 1,044 μg/kg. The percentage distribution of PAHs was predominantly 2–3 ringed PAHs ranging from 42.35 to 100 %. Samples obtained during the dry seasons of the year were also found to contain higher levels of total PAHs. Significantly higher total PAH concentrations were found at sampling points close to the main metropolis of Lagos compared with points in the lagoon which are far from the city, supporting the conclusion that urbanized and industrialized areas are major sources of PAH contamination in sediments.

The percentage distribution of grouped PAHs shown in Fig. 5 indicated a similar trend in all the sampling points. 2- and 3-ringed PAHs had the highest percentage distribution while the 6-ringed PAHs had the least. This indicated that the sediment samples in the Lagos Lagoon and the adjoining creeks had similar anthropogenic input of PAHs.

Table 5 Results of PAH analysis compared with standard pollution criteria of PAH components for sediment matrix

	Concentration (μg/kg) (Xu et al. 2007)		This study concentration (μg/kg)			
	ERL	ERM	Odo Iya alaro	Shasha	Ibeshe	Lagos lagoon
Naphthalene	160	2,100	446.26	164.45	143.86	138.56
Acenaphthene	16	500	105.09	29.99	45.65	14.76
Fluorene	19	540	41.68	46.47	50.96	36.03
Phenanthrene	240	1,500	138.91	99.53	129.95	148.50
Anthracene	853	1,100	99.51	71.44	170.21	57.98
Fluoranthene	600	5,100	268.60	229.67	164.28	295.16
Pyrene	665	2,600	198.13	153.21	136.72	241.94
Benzo(a)Anthracene	261	1,600	124.62	86.84	137.02	84.39
Chrysene	384	2,800	101.76	61.95	84.17	41.95
Benzo(b)Fluoranthene	NA	NA	176.87	88.42	94.65	70.36
Benzo(k)Fluoranthene	NA	NA	75.90	72.63	59.21	60.37
Benzo(a)Pyrene	430	1,600	73.14	54.61	88.43	44.93
Dibenzo(a,h)Anthracene	NA	NA	43.56	36.45	35.33	29.84
Benzo(g,h,i)Perylene	63.4	260	106.85	77.72	80.93	49.53
Indeno(1,2,3-c,d)Pyrene	NA	NA	100.10	66.42	84.06	61.49
∑PAH	4,000	44,792	2,334.16	1,213.31	1,449.82	880.43

Source identification of PAHs

Sediment samples collected near sewage outlets, cities and the harbour appeared to have extremely high concentrations of total PAHs. These suggest that PAHs accumulated in the sediments of the Lagos lagoon and the adjoining creeks came from different sources such as sewage discharge from nearby human activities, untreated industrial effluents and fuel combustion emissions.

The measured concentrations of PAHs were compared with the effects range low (ERL) and the effects range median (ERM) values which are used for assessment of aquatic sediment using biological thresholds with a ranking of low-to-high impact values (Long et al. 1995). Table 4 lists the thresholds for sediments from the Lagos lagoon and the adjoining creeks. In the sediments of the Odo Iya alaro, the results showed that the average total PAH concentrations at all sites were below the ERL and ERM (Table 5).

It is well established that PAH congener distribution generally varies with the production source as well as the composition and combustion temperature of the organic matter. Molecular indices based on ratios of selected PAH concentrations may be used to differentiate PAHs from pyrogenic and petrogenic origins. Four specific PAH ratios were calculated for the studied samples: phenanthrene/anthracene, fluoranthene/pyrene, benzo (a) anthracene/chrysene, and indeno (1,2,3c,d) pyrene/(Indeno (1,2,3c,d) pyrene + benzo (g,h,i) perylene).

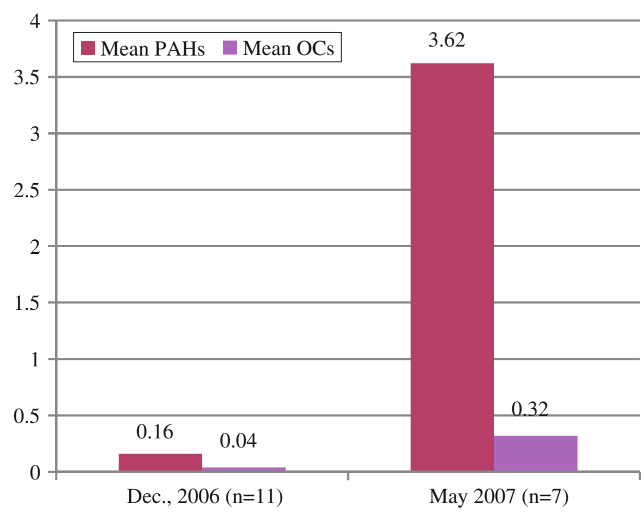
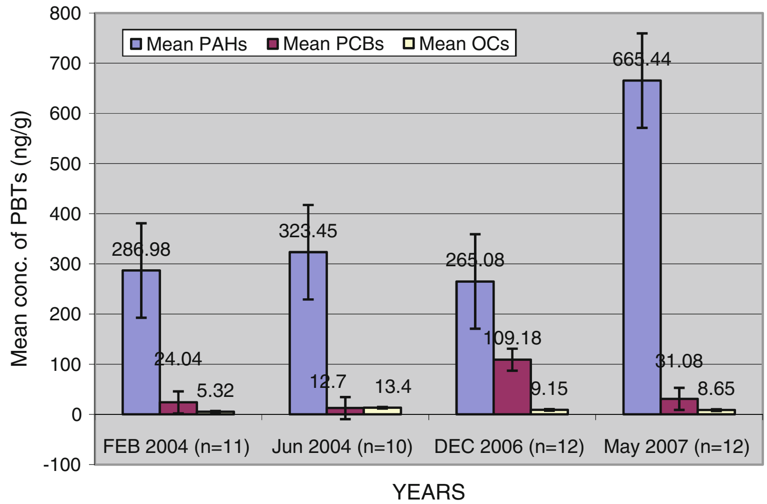


Fig. 6 Mean concentrations of PBTs (ng/mL) in December 2006 and May 2007 (PCB levels in Lagos Lagoon water during this study were below detection limit)

Results from the analysis of sediments of the Odo Iya alaro creek showed that Phe/Anth ratio ranged from 0.47 to 4.26. The ratios were mostly <1 except for a few sites. Flu/Pyr ratio ranged from 0.17 to 2.74. Most of the sampling sites had values less than 1, indicating pyrolytic origin or coal combustion. The BaA/Chr ratios were greater than 1 in

Fig. 7 Mean concentrations of PBTs in sediments from February 2004 to May 2007



most of the samples and could also be indicative of pyrogenic input of the PAHs. The pyrolytic PAH inputs at the Odo Iya alaro creek are also further confirmed by the IP/BgP + IP ratio. The values for this ratio ranged from 0.32 to 0.8 which is typical of fossil fuel combustion, coal, grass and wood combustion, all of which are pyrolytic sources. The results indicated that PAHs in the Odo Iya alaro had presumably undergone similar environmental processes independent of the sampling sites. A similar trend was observed in other sediments of the remaining sampling sites.

N-Alkane Distribution in Sediment Samples from Lagos Lagoon

The concentrations of total aliphatic hydrocarbons (C_9–C_{38}) in sediment samples from the Lagos Lagoon have been found to range from 14.89 to 148.29 µg/g dry weight, and their distribution showed large spatial variations at various sampling points. The distribution of both n-alkanes and PAHs shows great spatial variations in the sediments, which could be attributed to temporal and localized inputs of contamination sources. By examining the distribution indexes, it has been confirmed that the aliphatic hydrocarbons were mainly from anthropogenic to biogenic sources, while the distribution of PAHs came from both pyrolytic and petrogenic sources. The highest hydrocarbon concentrations in sediments were, in general, found in the areas associated with high anthropogenic impact and port activities.

The major hydrocarbon index in most samples was at C_{29}, C_{31} and C_{27}, indicating that vascular plant sources played a very important role (Wang et al. 2006). A lower molecular weight Cmax around C_{21} and C_{23} was also observed in several samples. CPI index ranged from 0.65 to 2.97 which indicated that the presence of n-alkanes in the Lagos lagoon sediments and the adjoining creeks was from both anthropogenic to pyrogenic sources. The sediment samples that had CPI values close to 1 were taken from areas associated with high anthropogenic impact and port activities such as Tin Can Island and Marina.

The temporal distribution of PBTs in the Lagos Lagoon is shown in Figs. 6 and 7.

Pattern of PBT Signatures Across Different Media in Lagos Lagoon, Nigeria

Our studies on the PBT signatures of the Lagos Lagoon System (Alani et al. 2012b) showed highest mean PAHs of 0.080 ng/ml in the lagoon water at the mouth of the Ogun River, a fluvial source, reflecting the effect of runoffs on the PAH load in the lagoon. In coastal areas, direct deposition of atmospheric PAHs may be relatively minor compared with fluvial inputs, but in open ocean areas it can dominate (Kowalewska and Konat 1997). The levels of PAHs in the lagoon water were also determined by Anyakora et al. (2004). The highest mean OCs of 0.069 ng/ml was obtained at Okobaba, a slum residence by the shore of the lagoon, where the use of pesticides for the control of insect vectors is relatively high. PCBs were not detected in water from the lagoon. In the sediment, highest mean PAHs of 68.251 ng/g d. w. was obtained at Okababa, highest mean OCs of 11.859 ng/g d. w. was obtained at Aja, while highest mean PCBs of 1.331 ng/g d. w. was obtained at the mouth of the Ogun River, confirming the effect of runoff load through fluvial sources. In the invertebrates, the highest mean PAHs of 18.659 ng/g d. w. was found in crayfish; the highest mean PCBs of 17.070 ng/g d. w. was found in crayfish; and

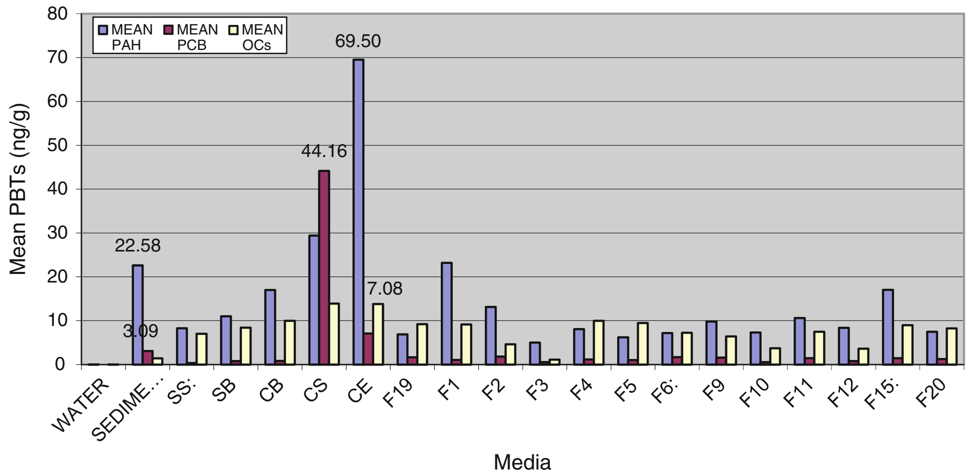


Fig. 8 Mean PBTs in different media of Lagos lagoon in December 2006 (Alani 2011), *Note SS* Crayfish, *SB Macrobranchium Vollenloevensi* (Shrimps), *CB Callinectus amnicola* (adult crabs, had eggs), CS *Callinectus amnicola* (young crabs), *CE* Crab eggs, *F1 Caranx hippos*(Agaza), *F2 Mugil cephalus* (mullet), *F3 Sphyraena barracuda* (barracuda), *F4 Saratherodon melanotheron* (Tilapia), *F5 Tilapia guineensis* (Tilapia), *F6 Edmalosa fimbriata* (Bonga), *F9 Tarpon Atlanticus* (megalops), *F10 Scomberomorus Tritor* (mackerel) (Ayo), *F11 Lutjanus agennes* (African red snapper), *F12 Pomadasys Jubelini* (Grunter), *F15 Chrysichthys Nigrodigitatus* (Catfish) (Obokun), *F20 Lutjanus Dentatus* (African *brown* snapper)

the highest mean OCs of 13.880 ng/g d. w. was found in young crabs. These patterns are most likely linked to their feeding habits, habitat, lipid contents metabolism ability and physiological characteristics among other factors. In the fish fillet tissues, the highest mean PAHs of 28.996 ng/g d. w. was found in agaza; the highest mean PCBs of 1.925 ng/g d. w. was found in mullets; and the highest mean OCs of 9.986 ng/g d. w. was found in tilapia (Fig. 8).

Conclusion

This paper has given an insight into the levels of pollution of the Lagos Lagoon with respect to PTE, nutrients and various other organic pollutants. The levels of some of the pollutants presently in the Lagoon has directly and indirectly affected the environmental, social and economical benefits derivable from the Lagoon. Indeed with the services expectation of the waterbody and the high population that the estuary/lagoon system supports, consideration of its designation as an international waterbody and its concomitant global attention is now paramount. It is important that strategies to ensure industries around the lagoon treat their effluents before discharging into the lagoon are needed. Also there is the need for the education of all stakeholders on the effects of indiscriminate dumping of municipal waste and burning of biomass around the Lagoon. Regulatory bodies must be encouraged to enforce existing regulations on municipal waste disposal and effluent discharge into this lagoon system.

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